STRONG SURFACE WINDS AT BIG DELTA, ALASKA

An Example of Orographic Influence on Local Weather

J. MURRAY MITCHELL, Jr.

Climatological Services Division, U. S. Weather Bureau, Washington, D. C.[1, 2]

[Manuscript received November 4, 1955; revised December 30, 1955]

ABSTRACT

The remarkably high frequency of strong surface winds in the region of Big Delta, Alaska, is studied with respect to its cause, characteristics, and local effects. During the winter, the winds are predominantly east-southeast and, unlike glacier or valley winds, are caused by a topographically induced convergence of the flow of air down the Tanana Valley which occurs at times of southeast gradient winds aloft. Strong south winds are also experienced the year round. A noteworthy characteristic of the east-southeast winds is their persistence; an extreme case is described in which gusts in excess of 40 m. p. h. endured for 7½ days (January 20–28, 1952). Another characteristic of these winds is the marked diurnal variation in the frequency of their commencement, by which a strong control by atmospheric tides is inferred. An important effect of the winds is to interrupt periods of very low temperature, but sometimes to create severe "wind chill." The paper concludes with a brief account of the forecast problem.

1. INTRODUCTION

Big Delta, located about 85 miles southeast of Fairbanks, Alaska, experiences a remarkably high frequency of strong surface winds. The weather records maintained there in recent years by the Civil Aeronautics Administration afford some insight into the cause, the characteristics, and some of the local effects of these winds. A study of the Big Delta winds is described in this paper which was prepared by the author preliminary to the development of an objective forecast study of the winds. Practical interest in the region is chiefly due to the presence of the United States Army Arctic Test Branch, which is charged with the testing of military supplies and equipment for adequacy and satisfactory performance under conditions of extreme Arctic cold; the winds comprise one of the more troublesome forecast problems in Alaska inherited by the Air Weather Service.

Surface wind roses for each month of the year at Big Delta are presented in figure 1. These serve to emphasize the following: (1) A very high frequency of east-southeast winds occurs in the colder part of the year (October through March), these winds being relatively strong. (2) An important frequency of *southerly* winds prevails throughout the year. (3) The percentage of calms during the winter months averages about 13 which may be contrasted with an average of more than 50 percent at nearby locations such as Fairbanks and Eielson Air Force Base which have nearly identical climatic temperature regimes.

[1] Paper presented at the 6th Alaskan Science Conference, College, Alaska, June 1955.

[2] Based on a study by the author when on active duty with the Air Weather Service. Verbally cleared for publication by Information Services, AWS.

2. CAUSE OF WINDS

The cause of the anomalously high frequency and speed of the east-southeast and south winds at Big Delta can readily be traced to the characteristics of the terrain there. Figure 2 delineates the general topography over southern Alaska and extreme western Canada. While Fairbanks is located in the broad Tanana Plain where the terrain is rather level, Big Delta is located at the southeast edge of the Plain, near the mouth of the long, relatively narrow valley in which the Tanana River flows from its headwaters. This valley is oriented approximately west-northwest—east-southeast, and while its floor rises gently about 1,000 feet from Big Delta to Northway, it is paralleled on either side by mountains which rise 2,000 to 7,000 feet higher.

When the weather pattern is such as to induce a southeasterly flow over the valley, and to set up a surface pressure gradient between Northway and Big Delta (with the higher pressures at Northway), air is funneled down this valley toward Big Delta with convergence sufficient to result in a surface wind current of strongly supergradient speed. This current, which has been likened to a jet stream against the ground, has been described by Ehrlich [1] on the basis of special aircraft reconnaissance in 1951. When blowing snow carried along by the wind makes the "jet" visible, it is apparent that (*a*) it is about 5 miles wide near Big Delta and perhaps 2,000 feet deep against the ground, and that (*b*) it does not break up as it enters the broad Tanana Plain northwest of Big Delta, but often continues across the plain like "a stream of water coming from the nozzle of a hose," and may stretch for more than 100 miles as it gradually broadens and diminishes in speed.

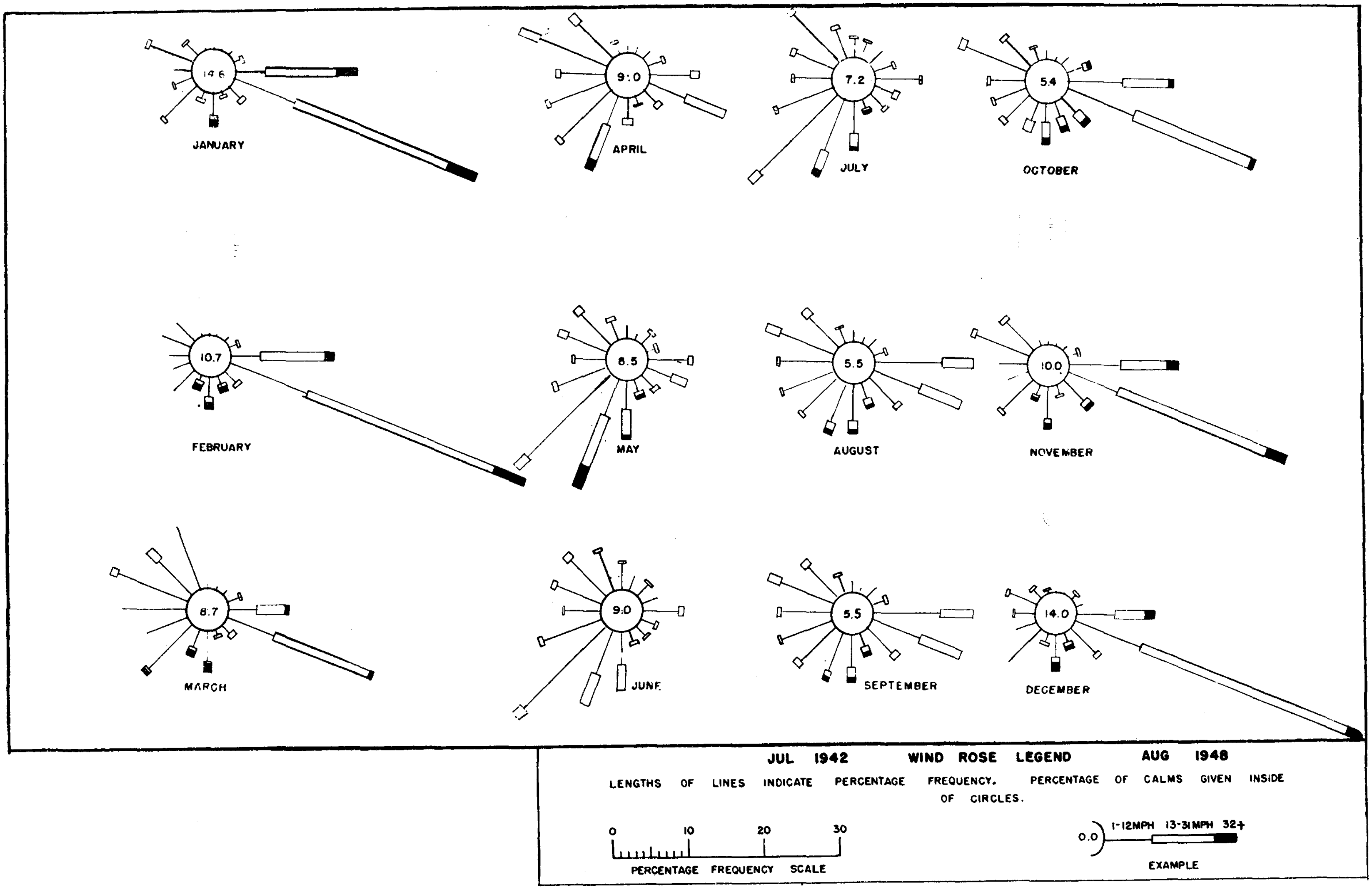

FIGURE 1.—Monthly wind roses for Big Delta, Alaska, based upon records from July 1942 through August 1948. Duplicated from a portion of a published climatology chart of the 7th Weather Group, Air Weather Service.

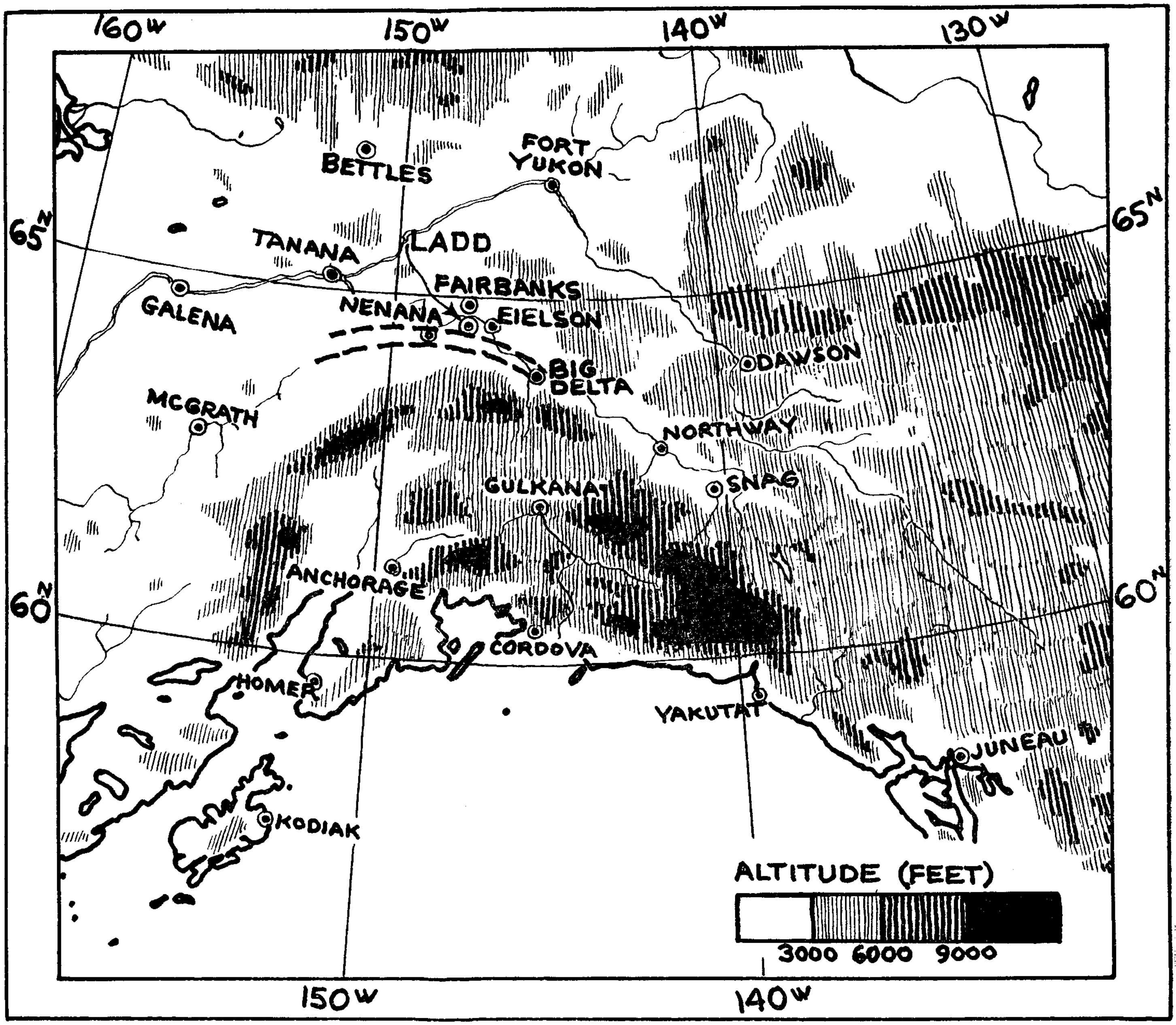

FIGURE 2.—Topography of south central Alaska. Dashed curves delineate the jet-stream-like surface wind in the position observed by aircraft reconnaissance in 1951 (Ehrlich [1]).

The "jet" has sometimes been observed to pass over Nenana, 110 miles to the west-northwest, where it has caused strong, gusty surface winds. On such occasions, Ladd and Eielson Air Force Bases located a few miles to the north of Nenana have experienced no wind whatever (note the "jet" position in fig. 2).

It is known that this current of air does not pass directly over Big Delta and the adjacent Arctic Test area with every occurrence. Slight differences in the pressure field south and east of the area cause the wind stream to vary its course and sometimes to bypass it. Moreover, it is likely that the "jet" meanders, and on that account gives rise to large variations in the strength of the surface wind at Big Delta.

To the south of Big Delta, at a distance of about 20 miles, lies a formidable portion of the Alaska Range which is locally interrupted only by a narrow pass, oriented north-south, through which flows the Delta River. In the pass, the adjacent mountains rise between 6,000 and 10,000 feet above the river; when the general weather regime results in a southerly or south-southwesterly flow over the Gulkana Basin to the south, a stream of air is usually forced through the pass, attaining highly super-gradient speed. This southerly current rather seldom passes directly over Big Delta. Owing both to the usual development and movement of pressure systems in Alaska, and to the exact orientation of the mountain pass itself, the current generally moves out into the Tanana Plain at

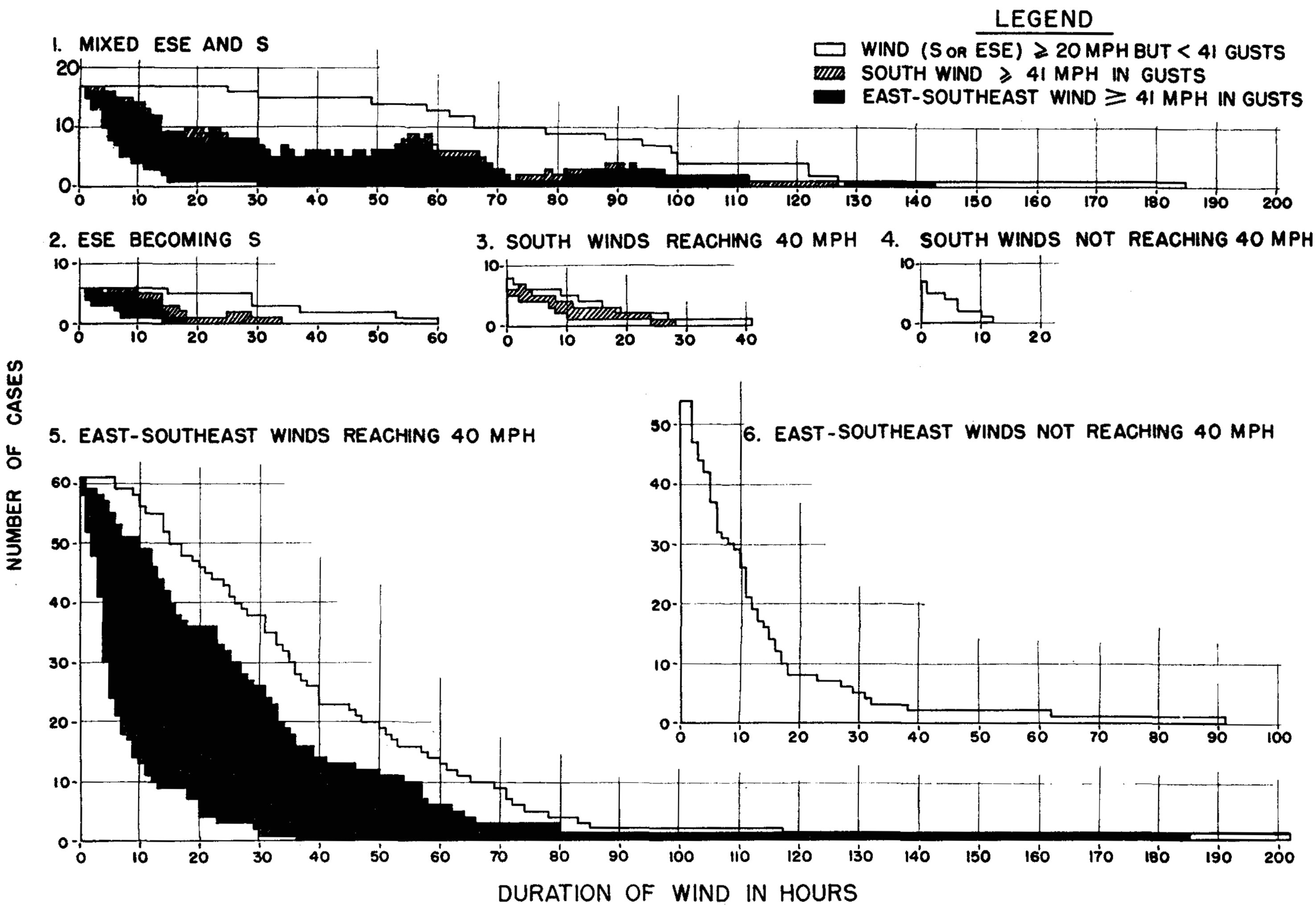

FIGURE 3.—Histograms of duration of strong winds at Big Delta during the colder months October through March. The winds have been classified, as indicated, into six categories determined by their direction and speed range. White area against the left-hand edge shows the decrease in frequency of winds, with increasing time of duration, which have not yet reached 40 m. p. h. in gusts. The solid black area adjoining shows the relative frequency of winds exceeding 40 m. p. h., as a function of elapsed time since the commencement of the 20-m. p. h. winds, The trailing white area reflects the frequency of 20-m. p. h. winds which followed the 40-m. p. h. winds, again as a function of elapsed time since the first occurrence of 20-m. p. h. winds.

a point lying to the west of Big Delta instead. The high incidence of strong *south* winds in the area must evidently be explained otherwise: Evans [2] has concluded that a strong, föhn-type flow of air directly over the Alaska Range is probably involved along with, or instead of, the current of air passing through the Delta River Valley. In support of this contention, Evans has observed that strong south winds at Big Delta are accompanied by a föhn-wall cloud formation over the mountains. Also, to be discussed presently, such south winds are accompanied by a very great temperature increase at the surface.

The weather situations giving rise to the strong east-southeast winds are not very different than those responsible for the strong south winds. When east-southeast winds are prevailing at Big Belta, south winds are often occurring just to the west, and a zone of convergence between the two currents can be found in the vicinity. These circumstances have been witnessed on several occasions by Evans as he was travelling over the network of roads in the Arctic Test Branch area. The south current is sometimes observed to encroach steadily into the region previously occupied by the east-southeast current, with the result that the reported wind at Big Delta may shift abruptly as the result of a gradual trend in the regional weather situation.

3. CHARACTERISTICS OF WINDS

A characteristic of the Big Delta winds which is worthy of particular attention is their duration. For purposes of describing duration, it is advantageous to separate occurrences of strong winds (defined as greater than or equal to 20 m. p. h.) into six categories:

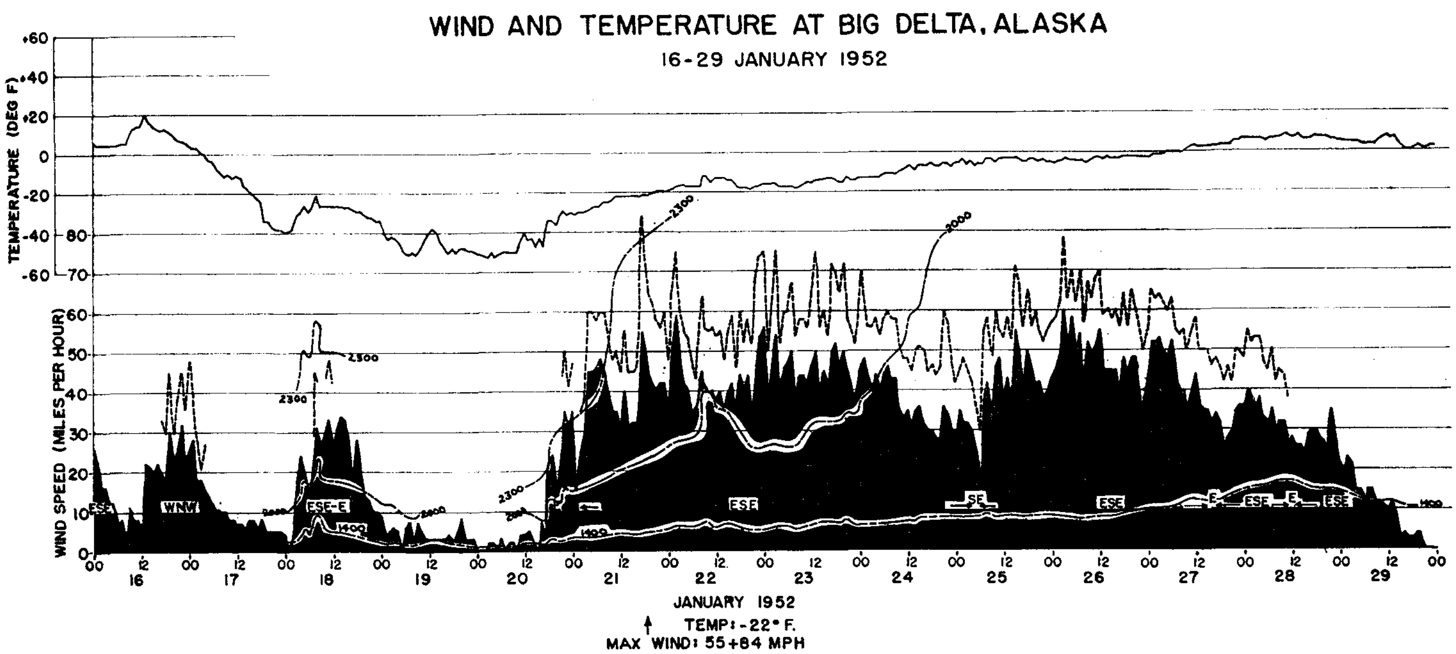

FIGURE 4.—Example of protracted duration of strong east-southeast winds at Big Delta showing variation in speed (fastest minute and gusts, which are dashed peaks), wind direction, temperature, and wind-chill factor. The wind-chill factor (sloping lines labeled 1400, 2000, and 2300) is plotted on the wind-speed graph as a function of concurrent temperature in order that the influence of the wind on human comfort during the storm can be readily seen.

(1) Mixed ESE and S winds (with gusts exceeding 40 m. p. h. from one or both directions, and usually both).
(2) ESE winds becoming S (usually with gusts exceeding 40 m. p. h. from both directions).
(3) S winds only which exceed 40 m. p. h.
(4) S winds only, greater than 20 m. p. h. but not exceeding 40 m. p. h.
(5) ESE winds only, which exceed 40 m. p. h.
(6) ESE winds only, greater than 20 m. p. h. but not exceeding 40 m. p. h.

In figure 3 are shown histograms of duration for each of the 6 individual classes, based on a total of 153 cases of wind in the four 6-month winter seasons 1949–50 through 1952–53. In these diagrams, the commencement of a wind is defined as the time of first observation (at the CAA station) of wind speed equal to or greater than 20 m. p. h. A few cases in which the wind reached 20 m. p. h. in a single, isolated observation have not been included in the data. Figure 3 serves several purposes. First, it shows that the most common type of wind (according to this classification) is that which blows invariably from the east-southeast, and which at some point in its history is likely to exceed 40 m. p. h. Second, it reveals the duration spectrum for each of the various categories of wind; e. g., in the case of east-southeast wind reaching 40 m. p. h., about 20 percent are still blowing above 40 m. p. h. at the end of 48 hours following the commencement of the wind. Third, figure 3 gives the probability that an existing wind will terminate or change in speed category in a given period of time, which can be applied both in the planning of operations affected by the strong winds and in the forecasting of temperature at Big Delta.

Occasionally an east-southeast wind of exceptional duration occurs. The most notable case of this type to occur in recent years was that of January 20–28, 1952, illustrated in figure 4. On January 20, a strong surface anticyclone located over the Mackenzie Basin was further intensified by the building up of a blocking ridge over the Bering Strait; the wind at Big Delta commenced from the east at 1800 Alaska Standard Time (0400 GMT, January 21). By 2100 AST the same day, gusts had reached 44 m. p. h. Then the surface wind veered to the more common direction of east-southeast, and with the exception of two periods of only two hours each, east-southeast winds gusting in excess of 40 m. p. h. persisted until 1000 AST on January 28. As is typical with the onset of east-southeast winds (see below), the temperature rose on January 20 by 22 Fahrenheit degrees from a low of −52° F. During the following 8 days, the temperature continued to rise rather slowly to a high of +8° F. on the 28th. The combination of high winds and relatively low temperatures made life at Big Delta rather hazardous. For the first 15 hours of wind, the wind-chill index [3, 4], which reflects the loss of heat from human skin in terms of cal/m^2 hr., was more than 2300. An index of 2300 is the point at which exposed areas of the face of an average person will freeze within 30 seconds. And for the first 86 hours (3½ days), the wind-chill index was continuously more than 2000 (the value at which a human face requires one minute to freeze,

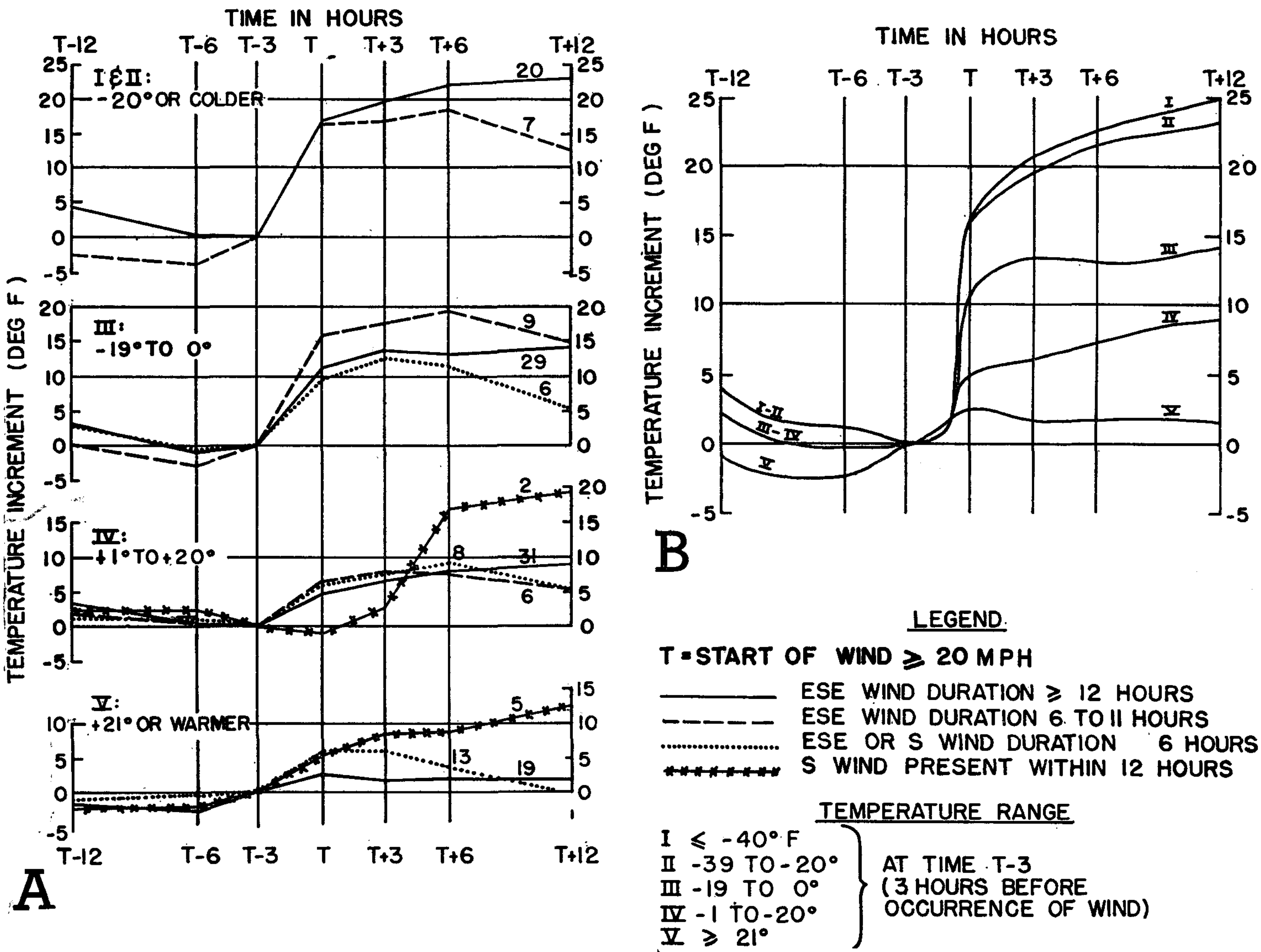

FIGURE 5.—Effect of winds on temperature at Big Delta, Alaska. The left side (A) shows, for each of five ranges of initial (3 hours before onset of wind) surface temperature, the temperature change caused by the inception of east-southeast and south winds of various durations as indicated. The right side of the figure shows, for the same ranges of initial temperature, the temperature change caused by the inception only of east-southeast winds which endure 12 hours or more. Here, the temperature changes have been interpolated more realistically between the computed data.

and travel or life in temporary shelter is described as dangerous). And for a period of 9 days, which included the period of strong winds, danger of frostbite was continuously present with the wind-chill index remaining above 1400.

4. LOCAL EFFECT OF WINDS ON TEMPERATURE

As mentioned previously, an important consequence of strong winds during the winter at Big Delta is normally to interrupt periods of low temperature. The wind is such a common occurrence there that the inhabitants take it rather in their stride. Too, the Army Arctic Test Branch is involved more with "cold-soaking" tests than it is with wind-chill or high wind, and when a wind impends, tests are usually suspended merely because the temperature will be increased above the desired level.

Figure 5 illustrates the relationship between wind and temperature. The first increase of wind to 15 or 20 m. p. h. causes an abrupt increase in the surface air temperature, presumably through the partial destruction of the Arctic inversion in the region by vertical mixing. Further increases of wind above 20 m. p. h. have the effect of very slight additional warming when the wind is east-southeast, but of strong warming when the wind is southerly.

The left-hand side of figure 5 shows the increase in temperature with the onset of winds equal to or greater than 20 m. p. h., for each of several ranges of prewind surface temperature. The different lines in the graphs identify the effect of four categories of wind defined as follows:

(1) ESE wind enduring at least 12 hours (whether or not they exceed 40 m. p. h.).

(2) ESE wind enduring for between 6 and 11 hours (some of which may exceed 40 m. p. h.).
(3) ESE wind enduring for less than 6 hours (sometimes with a brief period of southerly wind).
(4) Wind which becomes southerly within 12 hours (which starts as ESE, but which usually increases to above 40 m. p. h. from the south).

For particular temperature ranges, one or more of the above categories of wind are found to exist too infrequently to yield a statistically reliable average temperature trend, and these have been omitted. This part of figure 5 demonstrates that, with low temperatures before the onset of wind, there results a larger warming than with relatively high prewind temperatures. The duration of the wind plays a secondary role in determining the magnitude of the warming, and appears to affect the temperature to varying degrees chiefly after the time when some of the winds have ceased. The case of south winds is noteworthy, inasmuch as a greater warming results with them. Most of the southerly winds occurred with relatively high prewind temperatures, but one case also occurred in each of the colder categories (II and III). These have not been included in the figure. It is interesting that, with the south wind which occurred in category II (prewind temperature −22° F.), a warming of 36° F. resulted in 6 hours, 46° in 9 hours, and 47° in 15 hours. The case of south wind in category III also resulted in a sharp warming trend; it is likely that the magnitude of the warming with southerly winds as a function of prewind temperature is more or less proportional to the magnitude of the warming with east-southeast winds, and larger.

The right-hand side of figure 5 refers specifically to east-southeast winds having a duration of 12 hours or more, which is the most frequent category encountered. In this part of the figure, the warming which results from the onset of wind is shown for various ranges of prewind temperature, facilitating a comparison of magnitudes. Here, the temperature trends have been interpolated between computed values in a manner which shows their shape more realistically. Three comments on this diagram are appropriate:

(1) Comparing the relative magnitudes of the warming trends in the separate temperature categories, it appears likely that the curve for category I represents an approximate upper limit to this magnitude. The mutual closeness of the curves for categories I and II cannot be explained in terms of a clustering of temperatures in category I about its upper limit of −40° F. (The three cases included in this category yielded an average prewind temperature of −47° F., and the 17 cases in category II, −30° F.).

(2) The dip in temperature for categories I and II just before the commencement of the wind can be explained as the result of excessive radiational cooling. It usually happens that a period of calm precedes the wind and endures for several hours.

(3) The gradual falling off of temperature following several hours after the onset of wind in the high-temperature category V is apparently because most of the cases in the category came in the late fall and early spring when there is a noticeable preference for the winds to commence in the late morning hours. Accordingly, a diurnal temperature trend has been introduced into the data.

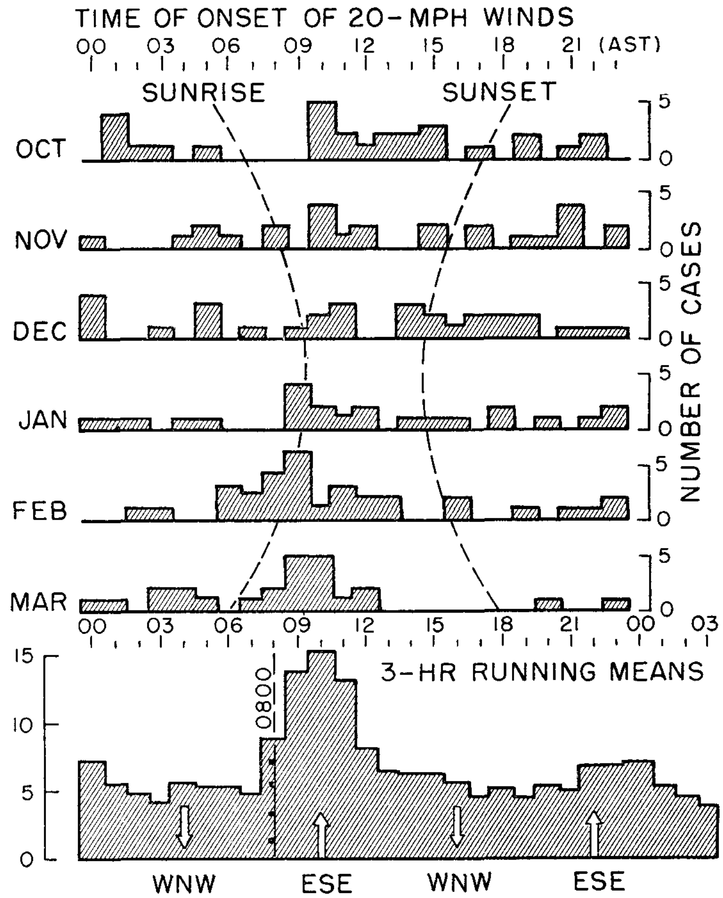

FIGURE 6.—Diurnal distribution of the time of onset of east-southeast winds at Big Delta (20 m. p. h. or more), in Alaska Standard Time. The upper part of the figure shows frequency distribution by months (4 years of data). The lower part shows the seasonal frequency distribution expressed as 3-hour running means. The arrows at the bottom of the figure denote the theoretically computed times of tidal accelerations which should affect wind frequency in the directions indicated.

5. DIURNAL EFFECT IN WIND FREQUENCY

Figure 6 shows, for all four 6-month seasons of data, the diurnal distribution of the first occurrence of wind from the east-southeast. It will be noted that in each month, with the possible exception of December, a preference for about 1000 AST exists. This tendency is brought out more forcefully by the seasonal totals of frequency as a function of the hour, which are shown at the bottom of the figure as 3-hour running means. The following remarks are pertinent to explaining this diurnal favoritism.

The approximate times of sunrise and sunset are indicated in figure 6 as a function of season. In contrast to the widely varying time of sunrise, the time of commencement of the winds is seen to be more or less constant

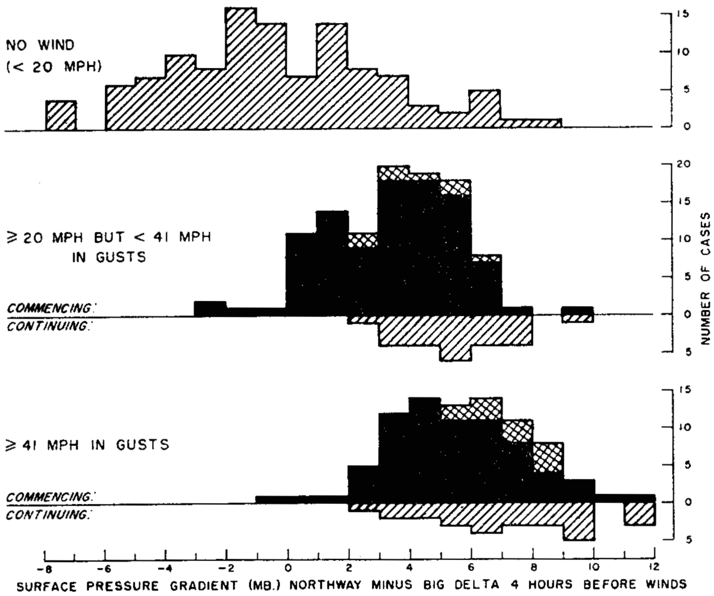

FIGURE 7.—Histograms of the magnitude of the surface pressure gradient from Northway to Big Delta which antecedes by 4 hours the inception of wind at Big Delta, with comparative histograms of the gradient for the case of "no wind" following (top of figure), and for the case of wind already in being and continuing (under-portions of lower two histograms). To obtain the correct relative number of cases in each category shown, it is necessary to multiply the frequencies in the hatched histograms by a factor of approximately 20. Cross-hatching refers to frequencies of initial south winds.

through the season. Moreover the sun is at such a large zenith angle during the middle of the winter that very little heating within the Arctic inversion can take place until the late morning.

At about 0800 local time, the sun is nevertheless able to reach the floor of the Tanana Valley between Northway and Big Delta during every month. Even at the winter solstice, some heating within the Arctic inversion in the valley may be expected at that time, causing minimum stability within the layer shortly thereafter. Allowing for a further delay before the winds at the surface are increased by vertical flux of momentum and conveyed down the valley to Big Delta, one might explain the 1000 AST peak in the onset of winds there.

The secondary maximum in frequency of onset of the winds to be found 12 hours later (from 2200 to 2400 AST) suggests that a tidal influence is involved. Through his computation of the tidal wind fields in the lower atmosphere, Stolov [5] shows that, for the latitude of Big Delta, a tidal wind component of more than one m. p. h. from the east-southeast may be expected at about 1000 and 2200 local time. Since the tidal vector rotates clockwise with a period of 12 hours, a wind component from the opposite direction is expected at about 0400 and 1600 local time. The phase of this tidal acceleration is shown by the arrows at the bottom of figure 6 where it may readily be compared with the diurnal variation in the commencement frequency of the wind. A relationship is strongly suggested.

Accordingly, it is the writer's belief that the peak at 1000 local time in the frequency of onset of east-southeast winds is the result of a combination of a tidal component to the wind down the Tanana Valley which is locally magnified by topographic convergence, with a maximum of turbulent transfer of momentum in the Arctic inversion in the valley induced by solar heating of the layer shortly before that time.

6. FORECASTING THE WINDS

For a number of years, an index of the imminent likelihood of winds (especially the east-southeast type) has locally been employed in forecast practice, consisting of the sea level pressure difference between Northway and Big Delta. When the Northway pressure exceeds the Big Delta pressure by 3 mb. or more, winds exceeding 20 m. p. h. may be forecast to commence or to continue, as appropriate, with fair confidence. Figure 7 illustrates the degree of relationship between the Northway-Big Delta pressure gradient and the subsequent occurrence of wind at Big Delta, wherein the gradient anticipates the wind by 4 hours. It is well known that the winds are strongly cross-gradient, as these pressure differences imply them to be. They are much more strongly cross-gradient in the case of a cyclonic pressure regime over the area than they are in the case of an anticyclonic regime.

Figure 8 depicts the synoptic weather types which are associated with the onset of Big Delta winds. Types A through E have to do with east-southeast winds, and Type S involves south winds. For illustration, the actual surface and 500-mb. patterns for selected dates (extracted from the U. S. Weather Bureau Historical Map Series) are shown superposed. It will be seen that the range of synoptic patterns conducive to strong winds is rather broad. In figure 8, their classification has been set up on the basis of a common trend in synoptic development, although it is desirable to emphasize that each type is generally independent of the others.

Type A (top, left) illustrates a rather common type which gives rise to protracted periods of strong east-southeast winds. A blocking ridge aloft over western Alaska is associated with a strongly developed surface High over the Mackenzie Basin, which remains stationary. A strong gradient of pressure exists to the southwest of the Mackenzie High, and near-gradient flow exists over Tanana Valley above Big Delta. The extreme stability of location of the blocking pattern often results in long duration of the wind.

Type B (top, center) illustrates the initial breakdown of a blocking ridge, or alternatively the incipient formation of a block. In this case, a weak frontal cyclone moves from the west into the Gulf of Alaska to reinforce the Gulf Low. Local displacement of the Gulf Low toward a moderately strong Mackenzie High—sometimes in combination with the passage of the upper portion of the migrating front—results in a brief period of wind.

Type C (top, right) illustrates the case of a closed High cell over the Arctic Ocean which is connected by essen-

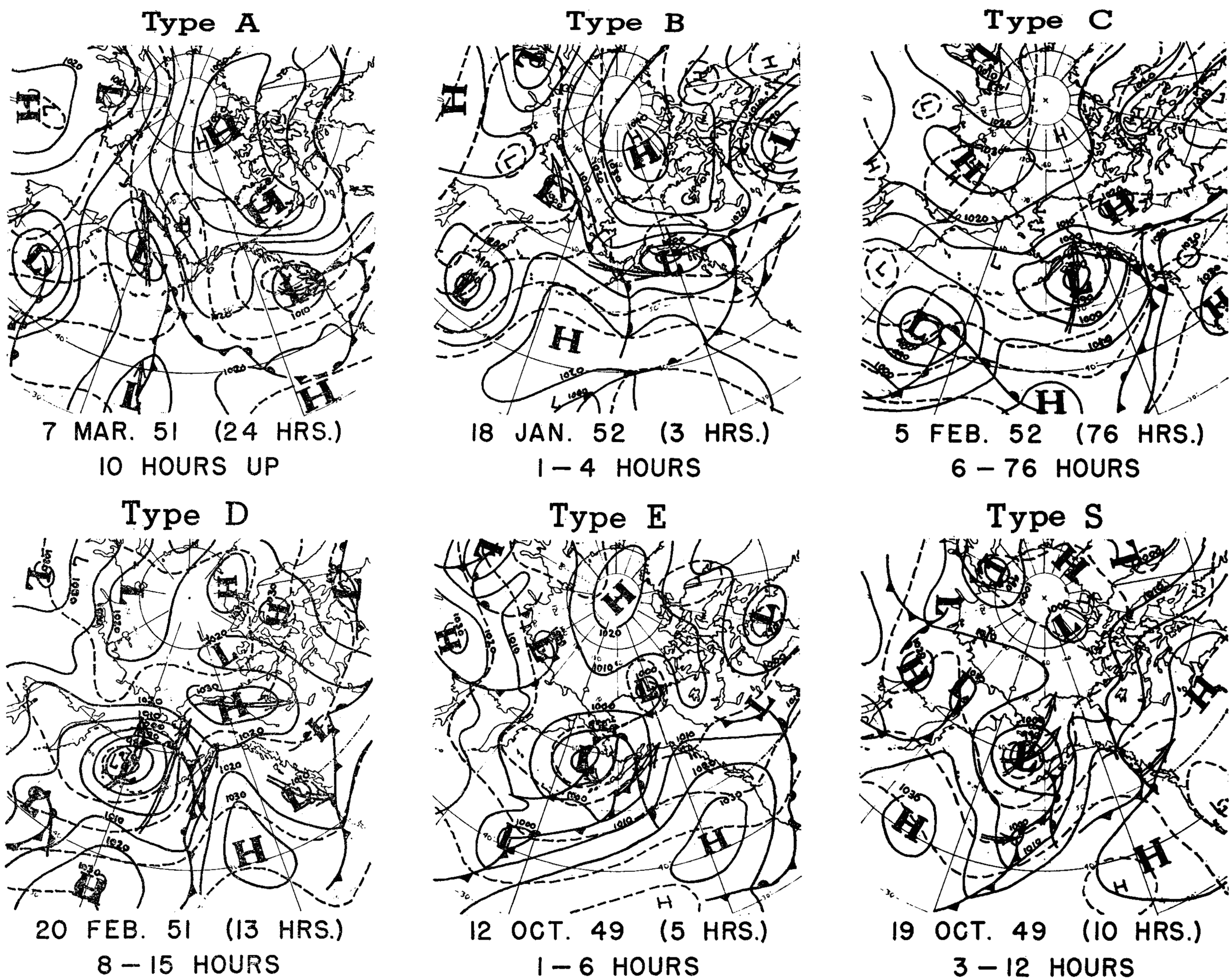

Figure 8.—Synoptic weather patterns in the vicinity of Alaska associated with the onset of strong winds at Big Delta. Types A through E are concomitant to east-southeast winds; Type S, to south winds. With each weather type is shown the date of the synoptic pattern used for illustration, the duration of wind at Big Delta on that occasion, and the usual range of duration of wind (> 40 m. p. h.) for that type. The 500-mb. pattern is shown by dashed contours at 400-foot intervals, and closed Highs and Lows aloft by small H's and L's respectively. Surface isobaric interval (solid lines) is 10 mb.

tially non-blocking ridges over the Rockies and/or eastern Siberia. The closed High aloft to the north helps to maintain a weak stationary Mackenzie High, while a zonal flow in the Pacific feeds deepening Lows into the Gulf of Alaska. The combination results in a tightened gradient over the Big Delta area which can result in moderately long duration of east-southeast wind.

Type D (bottom, left) illustrates a common case in which a large-amplitude, short-wavelength flow aloft moving across the Pacific brings rapidly deepening Lows into the Bering Sea and Bristol Bay, and intensifying migratory Highs across Alaska into northwestern Canada. The wind commences when the migratory High reaches the Mackenzie Basin, even though a Gulf Low is absent, and endures for a moderate number of hours. The movement of the High helps to distinguish this type from Type A.

Type E (bottom, center) illustrates a case typical of the late autumn. It is very similar to Type D in synoptic evolution with the exception that the Lows reaching the Bering Sea are not prone to deepen markedly, and consequently no ridge is built up over the Gulf of Alaska. The Mackenzie High, migratory or otherwise, is absent, and frontal systems penetrate northward across Alaska. In this type, the Big Delta wind is of brief duration, and occurs in advance of frontal passage.

Type S (bottom, right) illustrates the usual concomitant to south winds at Big Delta. Close parallelism to Type E is evident, but an important difference lies in the fact that the major storm center moving into the Bering Sea is favored to move more-or-less bodily across Alaska in a flow aloft which is stronger and more southerly than in the case of Type E. A strong southerly gradient is set up over the Big Delta region which usually results in a föhn-type wind at the surface. This synoptic pattern, in a somewhat weakened form, is very common during the warmer months of the year, a fact which serves to explain why strong south winds—unlike the east-southeast variety—are experienced all year at Big Delta.

ACKNOWLEDGMENTS

The writer wishes to record with appreciation the assistance of Maj. Albert Ehrlich, 7th Weather Group, Air Weather Service, for providing background information on the subject of this paper, and the assistance of Miss Alveda Nordling of the Regional Office, United States Weather Bureau, Anchorage, for providing microfilm records. He also wishes to thank Capt. James R. Evans, 7th Weather Group detachment commander at Big Delta (Fort Greeley), for his helpful discussions of local weather phenomena and for the supply of certain weather records to facilitate this study.

REFERENCES

1. A. Ehrlich, "Note on Local Winds near Big Delta, Alaska", *Bulletin of the American Meteorological Society*, vol. 34, No. 4, Apr. 1953, pp. 181–182.
2. J. R. Evans, personal communication, May 1955.
3. P. A. Siple and C. F. Passel, *Table of Wind-Chill Values*, Climatic Research Unit of the Office of Quartermaster General, Jan. 1943.
4. P. A. Siple and C. F. Passel, "Measurements of Dry Atmospheric Cooling in Sub-Freezing Temperatures", *Proceedings of the American Philosophical Society*, vol. 89, 1945, pp. 179–199.
5. H. L. Stolov, "Tidal Wind Fields in the Atmosphere", *Journal of Meteorology*, vol. 12, No. 2, Apr. 1955, pp. 117–140.